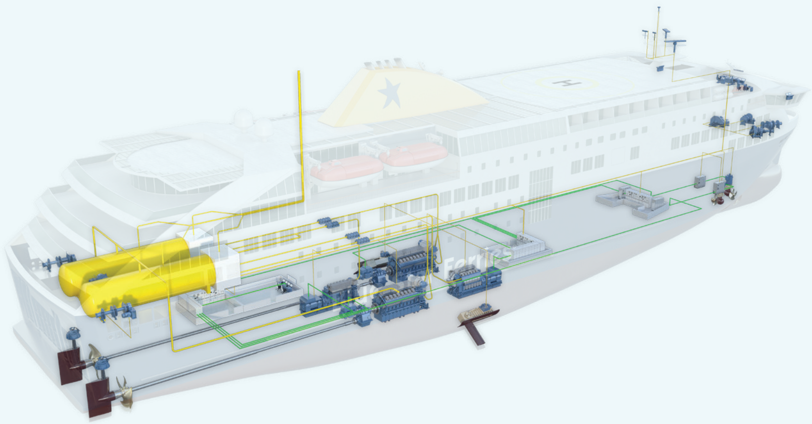
ROLLS-ROYCE BERGEN ENGINES

Kongsberg Maritime is the exclusive distributor for Rolls-Royce Bergen medium speed engines for Marine applications

KONGSBERG



ROLLS-ROYCE BERGEN ENGINES

LNG – a bridging fuel in the transition towards zero carbon emissions

It has probably never in history been more challenging for a ship owner to choose machinery and fuel system for the next newbuild. Focus on green fuels and zero carbon emission is increasing, but for carbon neutral fuels to become a real alternative to diesel and heavy fuel oil, the overall business case seen from the ship owner`s perspective, needs to make sense. Bergen Engines is introducing flexible engine solutions that can transition in parallel with the energy transition, ensuring that investments today are valid throughout the vessel's lifetime.

Hydrogen and other fuels made from it, such as ammonia and methanol, are considered the most promising options for maritime shipping. Ammonia is expected to become the main green maritime fuel of the future as it is far easier to store than hydrogen, and it takes up around half the space for the same amount of energy. But every conversion from one energy carrier to another requires energy, which will increase the fuel price, reduce the overall energy efficiency, and eventually reduce the environmental benefit. In addition, any carbon neutral fuel must be produced from renewable energy, nuclear power or carbon captured energy sources to reduce the net Green House Gas (GHG) emissions and be considered "green".

There are many challenges to overcome to obtain a decarbonised maritime shipping future. The main drivers to be successful are;

- Incentives such as CO_2 tax and compensation schemes to make green investments more attractive
- Standardised rules and regulations
- Acceptable prices of new fuels and bunkering availability
- Access to the right technologies

Governments are currently doing a lot to create regulations that support and promote the production of carbon neutral fuels, and at the same time reduce GHG emissions. Carbon free and carbon neutral fuels are exempt from the CO_2 tax. CO_2 taxes will help closing the cost gap between fossil fuels and green fuels and make the business case to invest in green fuels economically viable. The huge cost reductions in wind and solar over the past years are likely to decrease the prices for green fuels in the decades to come.

The International Maritime Organisation (IMO, a specialized agency of the United Nations), has with its 174 member states, a central role in defining the targets the maritime industry must reach and comply to. In April 2018, IMO set a target to reduce the total annual GHG emissions by at least (compared to 2008):

- 40% by 2030
- 50% by 2050

There are many measures that will contribute to meet this goal, the main factors being;

- Improved hull design and propulsion efficiency for less use of energy
- Optimized use of equipment with monitoring and support systems for less use of energy per operational mode
- Regular cleaning of the hull to reduce water resistance and thereby less power needed to maintain the speed and maneuverability
- Engines prepared for carbon neutral and carbon free fuels

Kongsberg Maritime offers a wide range of such products and solutions to help our customers to meet the overall IMO target and contribute to the reduction of global warming.

Energy optimisation

With the roll-out of CO_2-taxes, fuel efficiency will be even more important than today. The Bergen lean-burn gas engines deliver world class efficiency levels, without any dual-fuel compromise. Optimizing energy consumption is a win-win for both the shipowner and the environment. It's the right way to go to reach a more sustainable maritime future. Waste heat from the gas engines can be used for both heating and cooling of the interiors, increasing the efficiency levels by up to 93% of the energy input. Available technologies such as engine configurations with combined heat and power, and/or hybrid solutions with batteries can substantially help to reduce the environmental impact to an absolute minimum.

Pure LNG operated engines have an important role to play in the energy transition

It has taken approximately 20 years to establish Liquified Natural Gas (LNG) as a mature alternative maritime fuel, with the necessary rules and regulations in place, and bunkering facilities along the coastlines globally. LNG is readily available across the world, at an accessible price, making it viable also for deep sea transport.

LNG represents only approximately 1 % of the world fleet per end 2020 but is expected to grow significantly in the decades to come and represent between 30-35 % of the marine fleet in 2050. The numerous benefits with LNG have led to a steadily increasing number of LNG-fuelled ships since early 2000, especially in the ferry-, offshore-, tanker- and container segments. Bergen Engines pioneered several of these segments with its pure gas engines, and in 2021, maritime gas engine number 100 will be delivered, a proof of the increased popularity of this technology among shipowners worldwide.

The pure gas engine technology is well proven and mature, and customer feedback from owners who have already made the transition to LNG, has been overwhelmingly positive. Pure gas engines offer economic benefits through reduced fuel costs and less maintenance, often with a return-on-investment of the added CAPEX within only 3-5 years. Feedback on much cleaner engine rooms and cleaner machinery is an additional benefit compared to a diesel or heavy fuel oil setup. With a 92 % reduction in NOx emissions, the Bergen pure gas engines offer an immediate answer to the current IMO Tier III limits, and the Sulphur CAP of 0.5 %, without exhaust gas aftertreatment. LNG also offer close to 99 % reduction in particulates/smoke.

The Bergen gas engines have 18 % lower GHG emissions than equivalent diesel engines when including the methane slip factor (per 100 years cycle).

Methane slip

Methane slip is methane that evades combustion and is emitted via the exhaust and crankcase ventilation, and some argue that this is a showstopper for LNG as a low emission fuel. This statement needs to be met by some facts.

Unburned methane arises primarily from incomplete combustion, and from fuel concealed in crevices in the combustion chamber during compression. LNG consists of 85-95% methane, which is a greenhouse gas much more potent than CO_2. The global warming potential of methane compared to the same mass of CO_2 is according to EU reports 84 times CO_2 over 20 years, and 28 times CO_2 over 100 years. It's therefore important to minimize methane slip to fully benefit from LNG as a low emission fuel. Even when accounting for methane slip, the overall GHG reduction of the Bergen engines is 18 % compared to a diesel engine, over a 100 years period on a Tank-to-Wake basis.

Bergen Engines takes the methane slip issue very seriously and is continuously working on reducing it further. Since the first gas engine was released to the power generation market in 1991, and to the maritime market from 2006, methane slip has been reduced by approximately 80 %. Optimization of the combustion process and timing, improvements of the control system and the engines' efficiency, together with Cylinder Pressure Monitoring (CPM), are some of the initiatives that have contributed to methane slip reduction. Other measures considered, are to reduce the number of pockets where unburnt gas can be trapped in the combustion chamber and reducing the overlap of inlet and exhaust valve openings and timing of gas admission. Current methane emissions from Bergen lean-burn gas engines are as low as 1.5-2.0 g/kWh.

Bergen Engines has also implemented a closed-circuit crankcase ventilation, ensuring that all methane that escapes from the crankcase is recirculated back to the combustion chamber. Specific methane slip varies as a function of engine load, with a higher specific slip at lower loads. Marine vessels seldom operate on full load, but to maintain a higher load, the Bergen engines can be programmed to operate on variable speed. This means that the engine speed can be reduced, so that the load can be kept higher, adapting to changes in the vessel's power needs. This is also a benefit for the engine's efficiency, and we have seen vessels reducing fuel consumption by 20-30% with this setup. The low engine speed also has a beneficial effect on the propeller, making it more efficient.

The fuel pathways towards the 2050 target

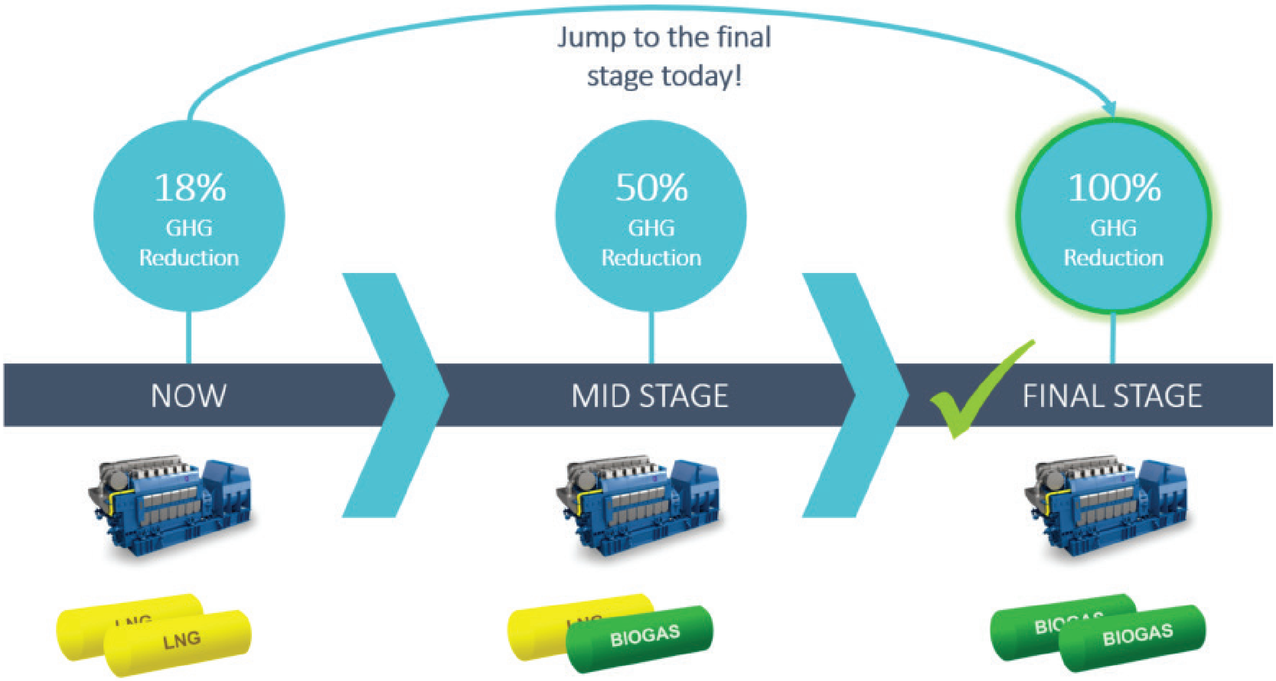
Carbon free synthetic fuels such as ammonia and hydrogen are likely to be used at a larger scale when there is a surplus of renewable energy for the production, or carbon capture and storage methods are fully applied (if produced from fossil fuel).

The energy transition will take time and happen at different speed depending on the regions. As most ships have a lifetime of 25-30 years, machinery chosen today must be able to operate on the least GHG intensive fuel that is available now and be able to transition to green fuels as they become available.

We therefore believe that the shift from fossil fuel to carbon neutral fuels will be best achieved by starting with an LNG engine set up today – and then gradually mix higher proportions of carbon neutral or zero carbon fuels with LNG, as they become available.

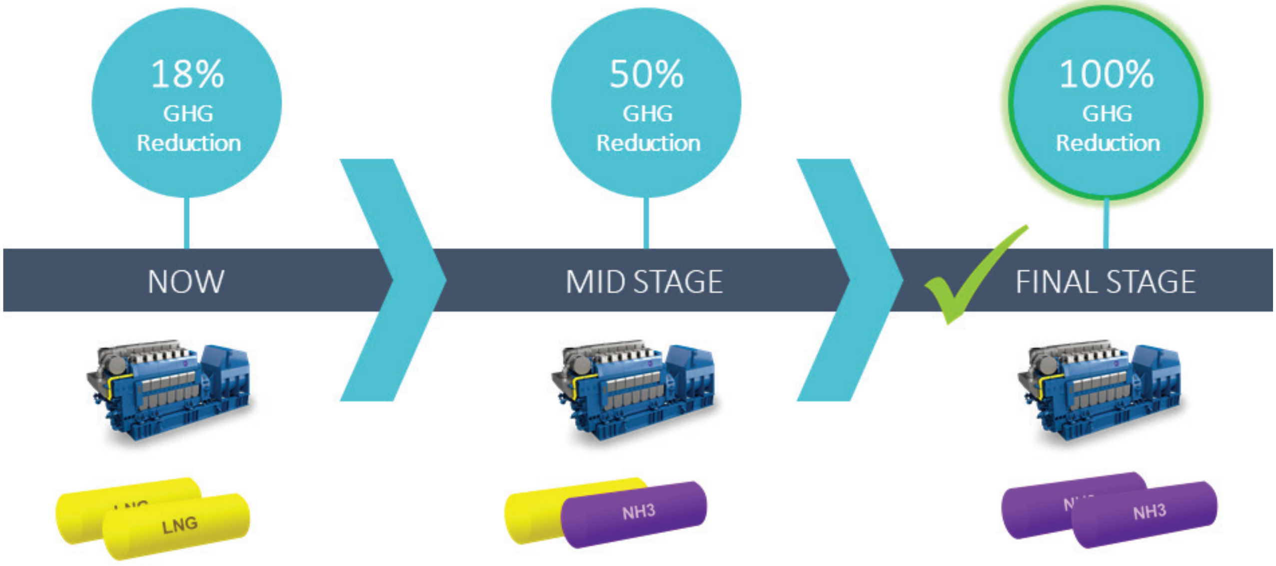
Depending on vessel segments, operational profiles, geographical regions and fuel availability, we foresee three possible fuel pathways starting from LNG, which could solve the 2050 CO_2 emission target, and eventually move to a carbon neutral/free final stage.

Pathway 1 - From LNG to liquid biogas (LBG)



- Carbon neutral solution ready today if biogas is available
- No need for modifications on the Bergen gas engine(s)
- No de-rating (subject to Methane (CH_4)>90 %) with possibility to blend with LNG
- Existing fuel supply and tank system can be used
- Efficiency and emissions are not affected
- Same safety barriers as for LNG

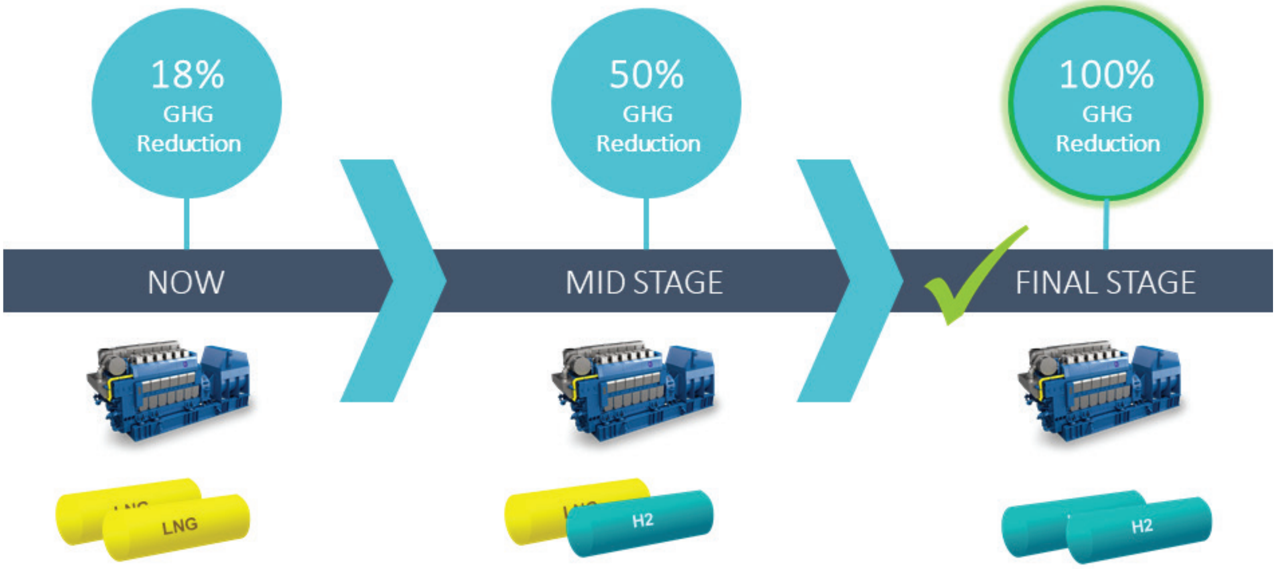
Pathway 2 - From LNG to Ammonia (NH_3)



- Zero carbon solution
- No de-rating
- Existing fuel supply and tank system can be used; ammonia tanks must be larger than LNG tanks due to a lower energy content of ammonia, and LNG tanks should be scaled accordingly
- Ammonia is toxic over a certain ppm level hence special measures needs to be designed in from the start
- Exhaust gas aftertreatment is required to handle NO_x emissions and N_2O slip
- Ammonia is corrosive and react to certain alloys, hence material selections needs to be carefully evaluated from bunker to combustion
- Need for modifications on the engine and fuel supply system
- Hydrogen cracker for combustion enhancement will be needed from mid-stage onwards
- Possibility to blend with LNG without modifications to the engine
- Efficiency is not expected to be affected
- It is recommended to have a load smoothing system for increased reliability, energy efficiency and safety, for example batteries

DNV GL has recently prepared a handbook on ammonia operation onboard ships, and it is expected that IMO will adapt the IGC code accordingly so that testing of ammonia operated ships can start. The handbook is a great tool for ship designers, so that all safety measures for bunkering, storage and use are considered already in the design phase.

Pathway 3 - From LNG to Hydrogen (H_2)



- Zero carbon solution
- Hydrogen is explosive hence safety measures related to storage, potential leakages, flammability and detonation energy must be implemented
- Liquified hydrogen tanks will be ~50% bigger than LNG tanks due to the lower volumetric energy density. Compressed hydrogen tanks will be almost 3 times bigger than LNG tanks
- We foresee the following steps of blending H_2 and which impact (if any) to the engines it has;
  - possibility to blend up to ~10 % hydrogen by volume with base gas at MN 80 or higher without modifications to the engine with today's engine setup
  - possibility to further increase hydrogen percentage up to ~60 % by volume through de-rating, without a retrofit needed
  - beyond ~60 % a need for a retrofit of the engine and fuel supply system is expected
- Further R&D development will provide more accurate figures and potential impact to existing engine setup
- Exhaust gas aftertreatment may be required to handle NOx emissions with high hydrogen volume blends

In general, if retrofits for any of the above pathways are done as part of a main service, much of the expense can be offset into the normal service cost. Most of the components that need replacement are in any case replaced or overhauled during a main service.

By choosing a Bergen gas engine for pure LNG operation as the first step towards neutral or zero carbon operation, you will have a flexible and highly efficient machinery that can be retrofitted to green fuels as they become available, meeting both existing and upcoming emission requirements, without the risk of stranded assets.

Kongsberg Maritime
P.O.Box 483, NO-3601
Kongsberg, Norway

Switchboard: +47 815 73 700
Global support 24/7: +47 33 03 24 07
E-mail sales: km.sales@km.kongsberg.com
E-mail support: km.support@kongsberg.com